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Next 1 Page(s) In Document Denied

Proceedings of USSR Academy of Science, April 1959
Physics Series, Vol. XX, No. 12, p. 7 (1956).

USE OF A PULSE IONIZATION CHAMBER IN AN ALPHA SPECTROMETER

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(translated by A. Ghiorso)

Arrangement and Performance of Chamber

The principle of operation of a pulse ionization chamber with electron collection is well known. The chamber used by us consisted of three electrodes (Fig. 1): high voltage (1), grid (2), and collecting electrode (3). The source of alpha particles was placed on the high voltage electrode. If the range of an alpha particle is confined to the volume between the high voltage electrode and the grid, then there is generated $N = \frac{E}{W}$ ion pairs, where E is the kinetic energy of the alpha particle, W is the average energy to form one ion pair.

The potentials on the high voltage electrode and grid are determined by the conditions: (1) avoidance of ion recombination, (2) securing the passage of electrons through the grid.

Through the action of the electric field the electrons move to the collecting electrode and within some time (~ 1 microsecond) all are collected on it. The positive ions, during this, stay practically in place, since their mobility is almost 1000 times less than that of electrons. The impulse on the collecting electrode is caused by the motion of the electrons, since from the action of the charge of the positive ions the collecting electrode is shielded by the grid; therefore, the amplitude of the impulse on the collecting electrode is equal to

$$V_1 = -\frac{Ne}{C_1},$$

where C is the charge of an electron, C_1 is the capacity of the collecting electrode relative to ground.

On the other hand the amplitude V_2 of the impulse on the high voltage electrode is determined by the positive ions. It is possible to show that

$$V_2 = \frac{Ne\left(1-\frac{x}{d}\cos\Psi\right)}{C_2},$$

where d is the distance between the high voltage electrode and the grid; X is the center of gravity of the ions along the track:

$$X = \frac{\int_0^R r\rho(r)dr}{\int_0^R \rho(r)dr}$$

($\rho(r)$ is the density of ions along the track); $\varnothing$ is the angle between the direction of motion of the alpha particle and the normal to the electrode; C_2 is the capacity of the high voltage electrode relative to ground.

The impulse on the grid is determined by the joint action of the charge of the positive ions and the electrons. A calculation showed that the impulse on the grid at first increases up to some negative value V_3, then decreases changes sign and by time t_1 becomes equal to

$$V_4 = \frac{Ne}{C_3} \cdot \frac{x}{d} \cos \varphi .$$

For alpha particles V_3, with a high degree of accuracy (~ 1%) is given by the formula:

$$V_3 = - \frac{Ne}{C_3} \left(1 - \frac{R}{d} \cos \varphi\right),$$

where R is the range of the alpha particle, C_3 is the capacity of the grid relative to ground.

Thus, the impulse V_1 on the collecting electrode is determined by the kinetic energy E of the alpha particle but the impulses V_2, V_3, and V_4 depend both on E and on cos φ.

A simultaneous measurement of V_1 and of one of the impulses V_2, V_3, or V_4 gives the energy of the alpha particle and the angle between the direction of motion of the alpha particle and the normal to the surface of the electrode. It is possible to take advantage of this for a solution of a series of physical problems and, in particular, problems of alpha spectroscopy.

Use of the Apparatus for the Measurement of Alpha Particle Energies

From the foregoing it is seen that using the impulse from the collecting electrode it is possible to measure the energy E of alpha particles.* Let us

*This method is satisfactorily widely used for the measurement of the kinetic energy both of alpha particles and of fission fragments. See, for example, [1-3].

consider the possible sources of error in the determination of E and let us estimate the resolving power of the apparatus. The resolving power is characterized by the half-width of a line of the alpha spectrum which are combined with δ (mean square deviation of the quantity V_1) by means of the correlation: half-width is equal to 2.35σ.

A. Mean Square Deviation of the Number of Ion Pairs δ_1

This error, associated with the fluctuation of the number of ion pairs of the generated ionizing particles, is the principle one. It is inherent to all ionization methods. Precise data relative to the value of σ_1 does not now yet exist. At present it is assumed[4] for computation that

$$\delta_1 = \sqrt{0.3 \cdot N}$$

where N is the number of ion pairs produced. This gives for ionization of argon by alpha particles with 5 Mev energy δ_1 = 6.6 Kev (which corresponds to a half-width equal to 16 Kev).

B. Mean Square Deviation δ_2, Dependent on the Preamplifier Tube Noise

In as much as the impulses originating at the collecting electrode are small in value (~ 1mv) it is necessary to amplify them. In addition there is the intrinsic noise of the first stage of the amplifier.

In the foreign literature a series of works[5,6] was published devoted to the construction of preamplifiers with low noise. The best results were obtained (see Reference 5) where σ_2 = 10 Kev (half-width 23.5 Kev).

We have succeeded in reducing δ_2 to 7.7 Kev (this corresponds to a half-width of 18 Kev).

C. Mean Square Deviation σ_3, Dependent on Losses in the Source

Alpha particles emitted by the bottom layers of a source, lose part of their energy in the layer and moreover the larger the angle to the normal at which they are emitted the greater is the loss. In order to make this error minimal it is necessary to record only the particles being emitted at a small angle to the normal. For the source used by us δ_3 = 2 Kev (half-width equal to 5 Kev).

Summing all the indicated errors according to the root mean square law we obtain

$$\delta = \sqrt{\delta_1^2 + \sigma_2^2 + \delta_3^2} = 10.5 \text{ Kev}$$

(this corresponds to a half-width of 25 Kev).

Thus the estimate obtained shows that if during a measurement there is not introduced any auxiliary apparatus errors then the half-width of an alpha spectral line should be equal to 25 Kev.

Apparatus Geometry

If one does not use a collimator then a chamber records approximately 50% of the emitted alpha particles. However, as it already has been shown, for the improvement of resolving power it is necessary to collimate the source of alpha particles. Up to now this has been done by a single method -- by means of a mechanical collimator. However, such a collimator possesses at least two substantial disadvantages: (1) the area of the source is not fully utilized so that the geometry is significantly reduced; (2) the fraction part of the ions that are produced in the openings of the collimator does not get to the collecting electrode so that the resolving power is impaired.

By taking advantage of a simultaneous measurement of the angle of flight and the energy of the alpha particle it is possible to introduce collimation without the use of a mechanical collimator.

It is possible to show that in the case of an isotropic distribution of alpha particles of the same energy, the differential distribution by amplitudes of the impulses V_3, for example, will be such as shown in Fig. 2, where along the abscissa is plotted the value of the amplitude of the impulses V_3 in volts and along the ordinate the number of impulses of a given amplitude. Along the abscissa is plotted also the value cos φ; cos ρ and V_3 are related in a linear fashion to one another. The impulses with minimum amplitude V_{min} are caused by the alpha particles emitted perpendicular to the surface of the electrode and the impulses with maximum amplitude V_{max} correspond to the alpha particles emitted parallel to the surface of the electrode. Hence it is evident that it is possible to introduce collimation by recording impulses V_1 in coincidence with impulses V_o occurring in the interval $V_{min} < V_3 < V_o \leqslant V_{max}$. It is obvious that by varying the value of V_o it is possible arbitrarily to change the degree of collimation.

Instead of V_3 the impulses V_2 or V_4 can also be utilized. By such a method of collimation the geometry is lowered not more than three to four times and amounts to 10-15%. It is interesting to contrast this data with that of a magnetic spectrometer. The geometry of the best magnetic spectrometers is ~ 0.02%. However, in the majority of cases the effectiveness of the spectrometers is determined not by the geometry but by the quantity Φ = IS (transmission) where I is the geometry

of the apparatus and S is the area of the source.

In magnetic spectrometers usually S ≈ 0.1 cm^2. However, in an ionization chamber the area of the source in principle is not limited (for example, a source used by us has an area of 75 cm^2).

Hence it is evident that the transmission of an ionization chamber is five or six orders of magnitude above that of a magnetic spectrometer and that it allows the study of the alpha spectra of elements with long half-life (low intensities), such as U^{238} and Th^{232}. In addition to this the resolving power of a chamber is only three to four times less than that of a magnetic spectrometer.

One more advantage of an ionization chamber is the feasibility of using a multichannel amplitude analyzer that permits the gathering of all points of a spectrum simultaneously under the same conditions. This is important during the study of the spectra of alpha emitters with a very short half-life (minutes, seconds, and even milliseconds).

In such a manner the impulse ionization chamber can be utilized for the study of the spectra of alpha emitters with a wide range of half-life.

In Fig. 3 is shown the spectrum of the natural mixture of uranium isotopes taken without collimation. This spectrum was obtained in 8 minutes.

In Fig. 4 is displayed how the use of collimation by the above described method improves the form of the spectrum. The counting rate during this run was reduced only three times. It should be noted that the actual relative intensities of the peaks in this figure are not preserved since the degree of collimation for U^{234} was set larger than for U^{238}. From a comparison of the spectra of Fig. 3 and 4 it is evident that by the introduction of collimation the tail on the low energy sides is sharply reduced and thanks to which the separation of the second group of alpha particles of U^{235} became possible. In Fig. 5 is shown the U^{234} peak using the same conditions described by the spectra of Fig. 4 but with narrower analyzer channels.

As is seen from Fig. 5 the half-width of the peak is equal to 35 Kev. This divergence from the expected value of 25 Kev we attribute to the instability of the loop oscillograph employed for amplitude analysis and also on account of insufficiently good shielding by the grid.

However there is also a principal reason which did not allow the resolution of the fine structure. The fact is that part of the group of alpha particles with low energy is accompanied by conversion electrons which produce additional ionization in the chamber volume. Consequently the impulses corresponding to such alpha

particles are larger than for other alpha particles of that same group.

In order to get rid of the conversion electrons we propose placing the chamber in a constant magnetic field. Then the conversion electrons will be returned by the field to the source without producing noticeable ionization in the volume of the chamber.

We think that in such an apparatus the study of rotational levels of alpha emitters will become possible.

Use of the Apparatus for the Study of α-γ Correlation

Since the chamber allows one to measure simultaneously the energy of an alpha particle and angle of flight it is natural to employ it for the study of α-γ correlation. For this it is necessary to record the differential distribution of one of the impulses V_2, V_3 or V_4 in coincidence with the impulses from a scintillation counter which registers the γ-quanta which are emitted perpendicular to the surface of the electrode. By a similar method Valladas et al.[7] first studied α-γ correlation. The authors used a two electrode chamber; consequently their method was useful only in the case when there is only one group of alpha particles.

However ordinarily there are present several groups of alpha particles. It is possible to separate one of them by the introduction of a coincidence with the impulses V_1 corresponding to this group. In Fig. 2 is shown the differential distribution of the impulses with grid V_3 in coincidence with V_1 corresponding to the energy E = 8.8 Mev of the alpha particles of ThC'.

In Fig. 2 it is evident that the experimental points agree well with the calculated curve (in the given case of alpha particles with an isotropic distribution). The error of measurement of cos φ is not more than 3%.

Once more let us make a comparison with a magnetic spectrometer. Just as for the energy measurement of alpha particles so also for the measurment of angular correlations the effectiveness of an ionization chamber can be four to five orders of magnitude higher than for a magnetic spectrometer. While not being inferior to the latter in accuracy of measurement of angular distributions, the chamber does not demand such complicated equipment, such as fast coincidence schemes, field stabilization, etc.

Everything points to the fact that the use of an impulse ionization chamber in place of a magnetic spectrometer for the study of α-γ correlations considerably shortens the time spent on measurements and in addition makes it possible to study the correlations for such elements where previously it was impossible.

The authors express deep gratitude to S. N. Nikolaev for valuable advice and aid during the construction and adjustment of the equipment.

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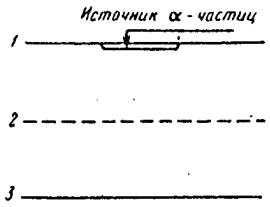

Рис. 1. Схематическое устройство камеры

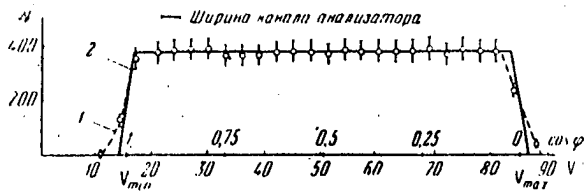

Рис. 2. Дифференциальное распределение отрицательных импульсов с сетки для α-частиц ThC' (E_α = 8,8 MeV): *1* — экспериментальная кривая, *2* — расчетная кривая с учетом ширины канала

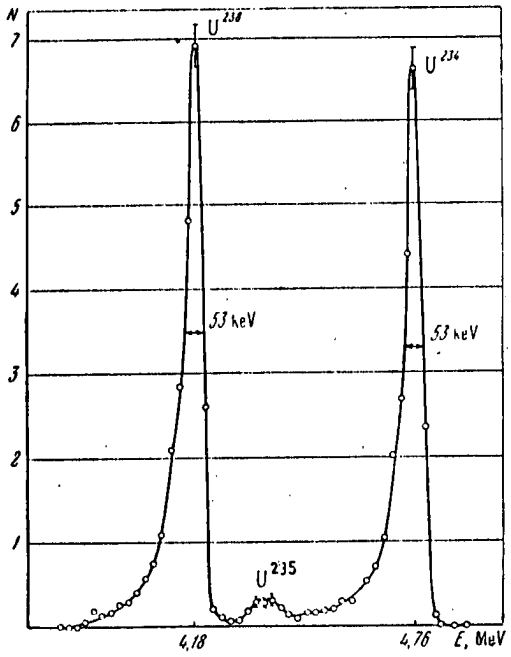

Рис. 3. Спектр естественной смеси изотопов урана, полученный без коллимации

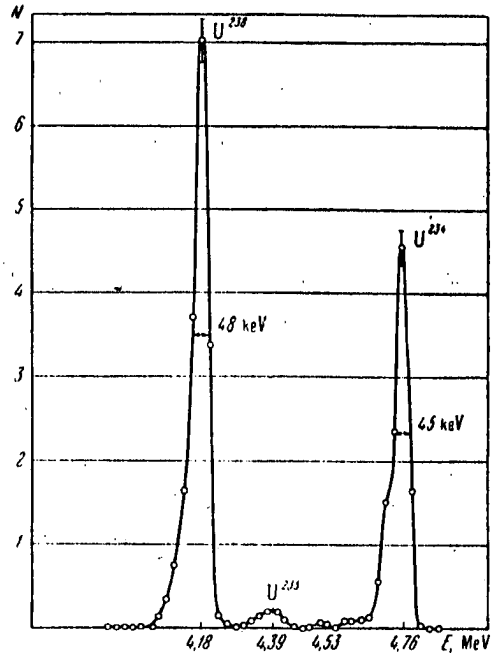

Рис. 4. Спектр естественной смеси изотопов урана; ширина канала 24 keV

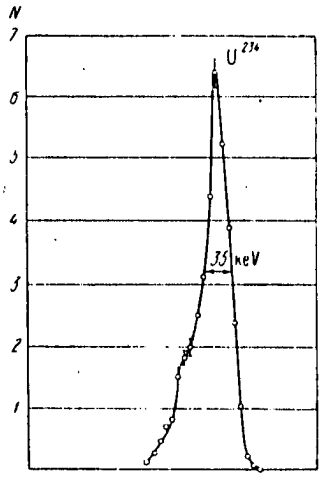

Рис. 5. Спектр U^{234}; ширина канала 8 keV